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Practical System to Monitor and Control the Penetration Depth of Welding by Submerged Arc Welding (SAW) with Multiple Electrodes†

IWATA Shinji[*1] NISHI Yasuhiko[*2] OZAMOTO Daisuke[*3]

Abstract:

High speed and high performance submerged arc welding (SAW) with multiple electrodes is used for the corner joint welding of box column for the structural steel fabricated in Shimizu Works. The authors have developed a system to control the penetration depth of the welding and its associated system, and have adopted them into commercial projects. It was confirmed that satisfactory and stable performance of welds, which was used to be highly dependent on the skill of experienced operators, have been achieved by the system.

1 Introduction

Submerged arc welding with multiple electrodes (multi-electrode SAW), which has the advantages of high efficiency and high speed, is widely used in flat position butt joints in fabricated steel, where the technique demonstrates its effectiveness. However, because the weld is covered with flux and cannot be observed when using this welding method, it is not possible to adjust the welding conditions during welding in response to the process, and therefore defects may occur. Furthermore, because the phenomenon of welding bead formation is also complex and involves numerous related parameters, theoretical clarification of welding phenomena is difficult, and methods of controlling welding conditions have not been established. For this reason, the experience and instincts of skilled operators are indispensable in securing stable weld quality. To solve this problem, the authors developed a system which controls the penetration depth uniformly and its associated system, using parameters (welding current, welding voltage, wire feed speed) which can be measured during welding, with the aim of improving welding quality in multi-electrode SAW and stabilizing forming of the weld bead[1)]. The introduction of this technology in welding shops has stabilized welding quality and enabled skill-free welding. The developed technology is introduced in the following.

2. Features of Multi-Electrode SAW

2.1 Features and Advantages of Multi-Electrode SAW

As shown in **Fig. 1**, the multi-electrode SAW method applied to corner joints of box columns is a method in which satisfactory welding quality and shape of the weld bead are secured using an arrangement of multiple electrodes (Fig. 1 shows an example of 3 electrodes.) at a constant distance in the direction of the welding line, by suitable arrangement of the electrodes and setting of the welding conditions.

A macroetch test specimen of the weld metal with this welding method is shown in **Photo 1** (example of 90 mm plate thickness).

The advantages of this welding method may be summarized as follows.

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*1 Group Manager, Welding Technic Group,
Shimizu Works Production Sec.,
Building Structure Engineering West Dept.,
Steel Structure Engineering Sector,
JFE Engineering


*2 General Manager, Nano-core Research Dept.,
Technical Research Center,
JFE Engineering


*3 Senior Researcher,
Production Engineering Research Dept.,
Technical Research Center,
JFE Engineering

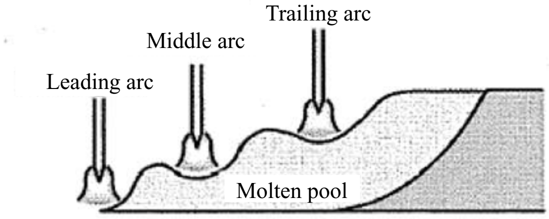
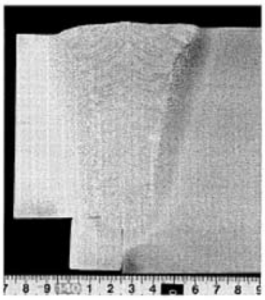


Fig. 1 Schematic section of the submerged arc welding with multiple electrodes



t=90 mm

Photo 1 Macroetch test specimen of welded metal by submerged arc welding with multiple electrodes

(1) Arc welding with deep penetration is possible.
(2) One run welding of thick plates is possible.
(3) High quality welding joints can be obtained with high efficiency.

2.2 Problems in Multi-Electrode SAW

Although this welding method has the advantages mentioned above, there are also problems in the application of multi-electrode SAW, as arranged below.

(1) Because the weld is covered with flux, welding phenomena cannot be observed during welding. As a result, it is not possible to adjust the welding conditions during welding in response to the condition of welding, and there are cases in which weld defects occur due to fluctuations in the groove shape, etc.
(2) As welding phenomena, the weld bead is formed by the action of the heat, pressure, and electromagnetic force of the respective electrodes on the same molten pool. Therefore, the setting angles of the electrodes, distance between the electrodes, polarity of the respective electrodes, distribution of the welding current, characteristics of the weld metal, and other factors have a large influence on forming of the weld bead. Because these welding phenomena are complex and involve numerous related parameters, an adequate theoretical clarification of the phenomena has not been achieved, and it has also been difficult to establish a control method for welding conditions.
(3) For the reasons mentioned above, the experience and intuition of skilled operators are indispensable in securing stable welding quality (including penetration depth).

3. Newly-Introduced Control System

The problems of the multi-electrode SAW method were studied, resulting in the development of (1) a welding condition control system in which multiple adjustment items used when setting welding conditions (total of 13 items, including welding current, welding voltage, and welding speed of each electrode) are input in advance and controlled automatically, (2) a penetration depth monitoring function which makes it possible to confirm the penetration depth during welding from the system screen, and (3) a penetration depth control system which automatically adjusts the welding conditions based on the monitoring data and controls welding penetration to a uniform depth. The corresponding control systems are introduced in the following.

3.1 Welding Condition Control System

This is a function that automatically controls the welding system to the welding conditions (preset conditions) set for each plate thickness. This function eliminates the conventional work in which one person set the welding current and voltage for 6 electrodes. This prevents errors in setting the standard welding conditions at the start of welding, setting delays, and similar problems, and thus realizes stable welding quality.

3.2 Penetration Depth Monitoring Function

This function enables monitoring of the penetration depth during welding in the system screen. This function makes it possible for even non-skilled operators to confirm whether welding is being performed under welding conditions suited to the plate thickness. Occurrence of various types of trouble is shown on the screen by color.

A data logging function using wireless LAN was also added to the system, making it possible to record the actual welding conditions and penetration depth monitoring values in all welding. **Figure 2** shows an example of a monitoring screen.

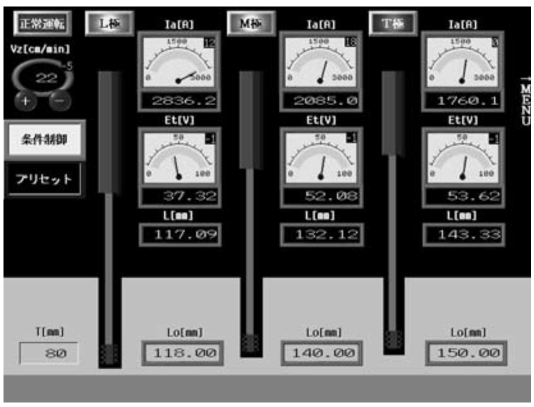


Fig. 2 Part of monitoring screen

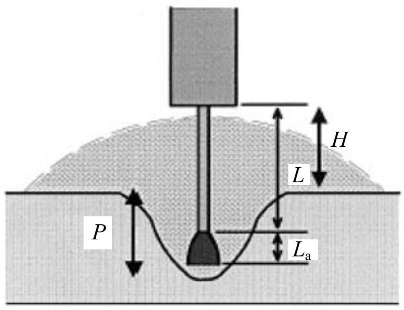


Fig. 3 Parameters to predict the arc position

3.3 Penetration Depth Control System

This function automatically adjusts the welding conditions based on the penetration depth monitoring data and controls the penetration depth to a uniform value. This makes it possible to reduce the width of fluctuations in the penetration depth in each joint in multi-electrode SAW of box column corner joints. The concept of the penetration depth control method is described below.

3.3.1 Estimation and control of penetration depth

The arc position is defined as the sum ($L + L_a$) of the wire extension (L) and arc length (L_a), and is calculated from measurable parameters (welding current, welding voltage, wire feed speed). Penetration is controlled by adjusting the welding current so that this estimated arc position is the correct value as set in advance. **Figure 3** shows the parameters used to predict the arc position.

3.3.2 Relationship of arc position and penetration

(1) **Figure 4** shows the relationship between the arc position and penetration when welding flat plates. From this, the arc position and penetration show substantially the same values, confirming that the relationship is as expected.

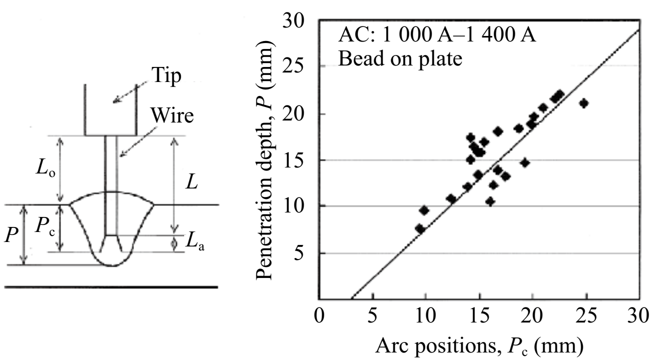


Fig. 4 Comparison between the prediction and the actual penetration depth by SAW

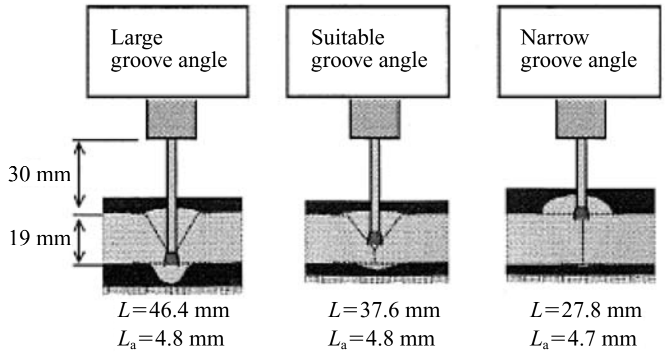


Fig. 5 Relationships between arc positions and penetration beads

(2) **Figure 5** shows the relationship between the results of monitoring of the arc position and the shape of the penetration bead on the back side (equivalent to the penetration depth) in one side welding. The expected relationship between the estimated arc position and the shape of the penetration bead on the back side was confirmed.

4. Study of Application to Corner Joints of Box Columns

Application of the developed control method to welding of corner joints of box columns was studied. When welding corner joints, penetration is identical to the penetration depth of the leading electrode. Therefore, for electrode control in this type of welding, penetration control is limited to the leading electrode, and the other electrodes are only monitored. As joints which are subject to control, control was implemented by selecting grooves with a larger root face and grooves with a larger root gap, considering error in the accuracy of the grooves. As a result, in grooves with a larger root face, satisfactory control was realized by adjusting the current corresponding to the condition of the groove, and in grooves with a larger root gap, control had been performed by changing the current as the root gap increased. These results confirmed that the penetration control method using the arc position during welding (monitoring values) functions in a basically satisfactory manner. **Photo 2** shows a macroetch test specimen of the

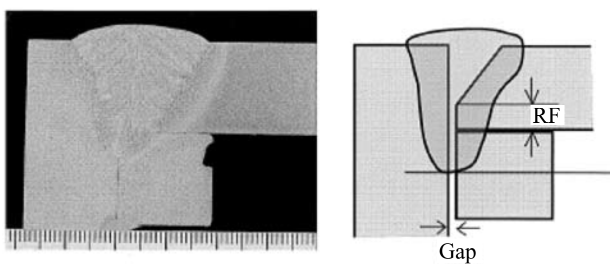


Photo 2 Macroetch test specimen of corner joint for box column

weld metal in a test.

5. Application to Shop Welding System

5.1 Improvement of Welding System

When this control system was incorporated in a shop welding system, addition of the following improvements enabled application to actual projects.

(1) Installation of Welding Monitoring Control System
The functions of welding condition presetting, arc position monitoring, and welding condition control were incorporated.

(2) Installation of Data Logging System
Functions of welding data collection by wireless LAN and monitoring of the welding condition during welding.

(3) Improvement of Wire Feed System of Middle Electrode/Trailing Electrode
Change of wire feed motor, fabrication of gear box, and fabrication of wire feed control system.

5.2 Application to Actual Projects

The developed control system was applied to welding of the corner joints of box columns in actual projects. As a result, (1) welding was possible under stable welding conditions from the start of welding to completion, even with groove fluctuations and similar conditions, (2) welding condition setting and adjustment work by the welding operator were reduced, allowing more time for attention to other monitoring items, and (3) early mastery of the operating procedure by non-skilled operators was possible. As a result of these improvements, it was possible to obtain good results in both the appearance of the weld bead and welding quality (confirmed by ultrasonic testing) in the corner joints of box columns. Accompanying stabilization of penetration, the uniformity of the appearance of the bead also improved over the full length of welds. **Photo 3** shows an example of application to shop welding in an actual project.

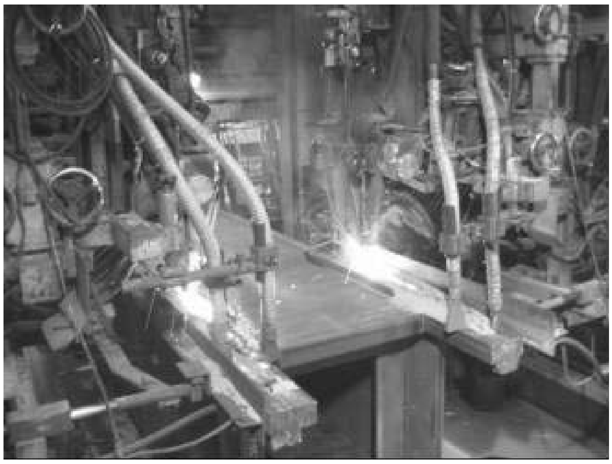


Photo 3 Application to actual project

6. Conclusion

This report has described the development and practical application of a welding condition monitoring and penetration control system for submerged arc welding (SAW) with multiple electrodes in welding of the corner joints of box columns for structural steel. Among other benefits, the introduction of this system has demonstrated effectiveness in securing stable welding quality and enabling early mastery of operating procedures by non-skilled operators.

Reference

1) Nishi, Yasuhiko et al. “Wire Melting Phenomena and Application for Penetration Control on deep penetration SAW.” Report of Technical Commission on Arc Welding Physics of JWS. 2006, no. 1291. (In Japanese)